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# HYDROGEN SAFETY TRAINING FOR RESEARCHERS AND TECHNICAL PERSONNEL

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## ABSTRACT

We are developing two hydrogen safety classes each respectively directed to laboratory researchers and technical operators. Laboratory researchers who need basic hydrogen safety information may now benefit from a 4-hour web-based hydrogen safety class (free online access at <http://www.h2labsafety.org/>) addressing hydrogen fundamentals: properties, pressure and cryogenic safety, emergency response and codes and standards. Technical operators in charge of building and testing experimental hydrogen equipment will also soon benefit from a more comprehensive 3-day hands-on safety class that will present detailed information for installation, testing and operation of hydrogen pressurized systems. The hands-on class includes a full day of classroom instruction followed by two days of laboratory work where students assemble, test and operate a pressure system based on a schematic and component description. We strongly encourage participation of the hydrogen community to improve the technical and educational aspects of the classes by providing feedback and comments.

## 1. INTRODUCTION

Hydrogen's properties differ substantially from those of conventional chemicals and fuels, such as methane, propane or gasoline. Among hydrogen's unique characteristics, we can cite its very wide flammability limits in air, low ignition energy, and low density leading to considerable buoyancy. Hydrogen is also odorless, tasteless and its flame is almost invisible in daylight. As a consequence, safety practices recommended for conventional chemicals and fuels are frequently not applicable to hydrogen.

The Hydrogen Safety section (3.8) of the U.S. Department of Energy (DOE) Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan [1] has recognized the need for hydrogen-specific training, identifying the lack of hydrogen knowledge and training opportunities among its technical barriers: Variation in Standard Practice of Safety Assessments for Components and Energy Systems, Lack of Hydrogen Knowledge by Authorities Having Jurisdiction and Lack of Hydrogen Training Facilities. DOE has therefore funded multiple safety training programs, including online safety knowledge tools (<http://www.h2bestpractices.org>) [2] and hydrogen safety training for first responders (<http://hydrogen.pnl.gov/FirstResponders/>) [3].

The European Commission has also participated in this educational effort by creating a network of excellence for hydrogen safety, HySafe [4], aimed at achieving safe introduction of hydrogen as an energy carrier and the removal of safety related obstacles. Many initiatives have taken place within HySafe, such as safety and risk studies (e.g. simulation of hydrogen release in a garage [5]) and organization of training and educational programs (e.g. international curriculum on hydrogen safety engineering [6]).

More recently, Lawrence Livermore National Laboratory (LLNL) has joined the effort by developing training materials for two important and previously overlooked groups of hydrogen users: laboratory researchers and technical personnel in charge of building experimental equipment. LLNL is working on classes that address the safety needs of these groups. *Laboratory researchers* handling small amount of hydrogen may now benefit from basic information on pressure, cryogenics, flammability, asphyxiation, and other risks and precautions in using hydrogen. A web-based class has been developed as an efficient way to transmit necessary information for safe operation, addressing:

hydrogen properties, pressure and cryogenic safety, emergency response and codes and standards, all in approximately four hours. *Technical personnel* in charge of building experimental equipment need comprehensive instruction on components, system design, assembly, leak testing, and operation. A 3-day hands-on class will teach the necessary skills for this demanding work.

## 2. WEB-BASED SAFETY CLASS ([www.h2labsafety.org](http://www.h2labsafety.org))

We have developed a web-based class with basic hydrogen safety information for researchers available at: <http://www.h2labsafety.org/> (free access). The electronic format of this class has been designed to reach the maximum amount of members of the hydrogen community around the world. The class takes ~4 hours for completion, and includes six modules (Table 1).

Table 1. Structure of the web-based safety class. Modules 2-6 are each followed by a quiz.

<b>Modules</b>	<b>Estimated Time</b>
1. <i>Introduction</i> Course description, navigation, study guides	10 minutes
2. <i>Hydrogen properties</i> Buoyancy, dispersion, ignition, flame and leak detection, ventilation, ignition sources, protective equipment	30 minutes
3. <i>Pressure safety</i> Pressurized systems, system components, stored energy considerations and calculations, basic design criteria, material properties, pressure ratings, safety factors, gas cylinder use and storage	90 minutes
4. <i>Cryogenic safety</i> Cryogenic fluid properties, thermal hazards, pressure hazards, expansion charts, asphyxiation, liquid air, safety measures	30 minutes
5. <i>Emergency response</i> Hydrogen posted signs, alarms, emergency crews, emergency instructions	30 minutes
6. <i>Codes and standards</i> Importance, organizations developing codes relevant to hydrogen, applicability, local and external resources	30 minutes

This class starts by highlighting basic handling precautions for hydrogen use as they relate to its chemical and physical properties. The *hydrogen properties* module summarizes the main physical and chemical properties of hydrogen: density and buoyancy, flammability and explosive properties, ignition conditions, etc. The module helps understand the necessary precautions for creating a safe environment when using and handling hydrogen. Hydrogen accumulation, combustion hazards, leak detection, ignition and exposure controls are also discussed in this module.

Pressurized systems, including those containing hydrogen, store tremendous amounts of energy. That energy, if released incorrectly, is the major safety concern associated with these systems. The *pressure safety* module (Figure 1) will assist in recognizing general pressure system safety issues and will introduce considerations specific to system components exposed to hydrogen. Given the importance of pressurized systems in laboratory work, this module is the longest and most demanding of the class. Topics include: system components (regulators, valves, relief devices, fittings, tubes, pressure gauges), expansion energy, system design considerations, hydrogen embrittlement, material verification, mechanical and thermal stresses, and component selection. Due to the length of the module, practice quizzes are included at relevant locations for improved learning and practice for the final module quiz.

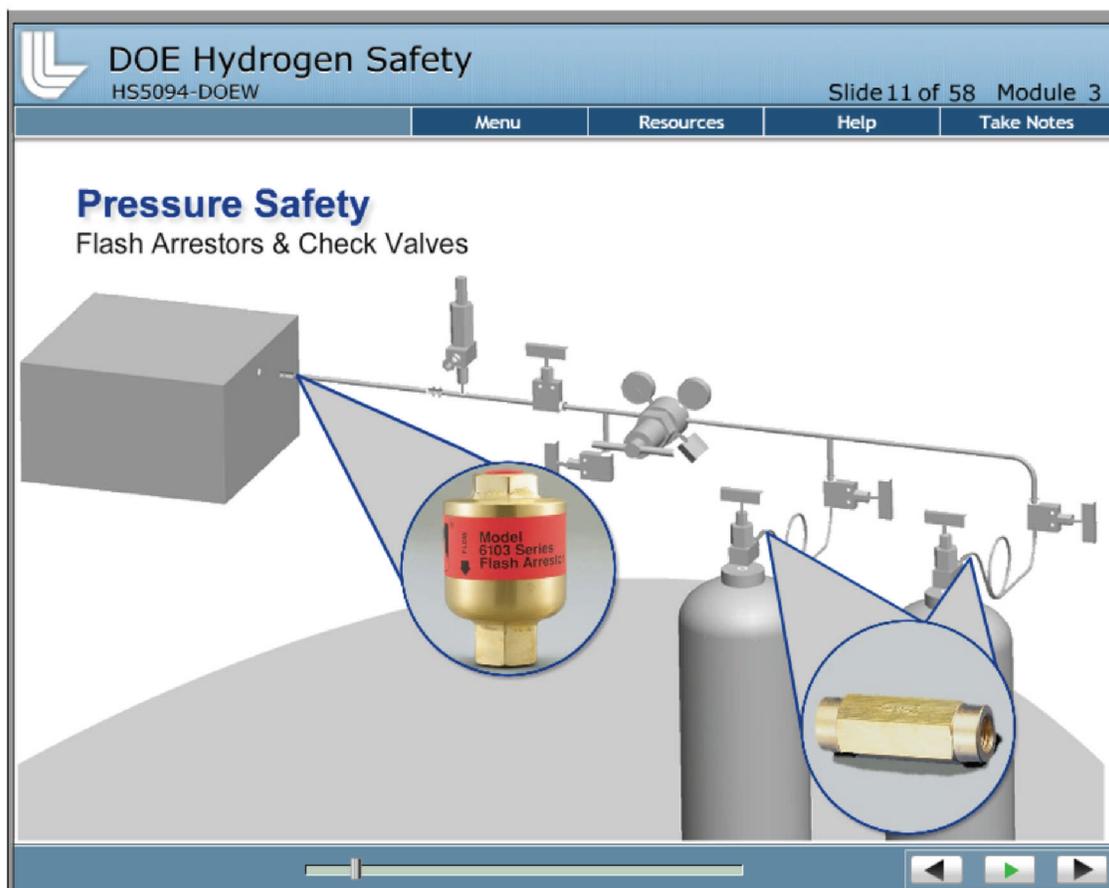


Figure 1. Screen image from the web-based class pressure safety module

The *cryogenic safety* module explains the hazards associated with liquid hydrogen and other cryogenics and the controls used to create a safe environment. Liquid hydrogen at its saturation temperature (20 K) is cold enough to freeze human tissue, causing severe frostbite. It also has the potential to liquefy air, leading to potential oxygen enrichment. Potential pressurization due to environmental heat transfer is also a key issue demanding special design and construction. Ice buildup and asphyxiation are other important hazards that need to be properly mitigated.

The *emergency response* module discusses warning signs, steps to be taken in order to respond to the emergency, and types of equipment needed to address an emergency situation involving hydrogen. The module discusses emergency responses to hydrogen release and/or fire.

The last module, *codes and standards*, provides a brief overview of codes and standards applicable to hydrogen systems, and is intended to increase awareness of the safety requirements related to hydrogen and pressure systems.

Navigation through the class is simple: from any location the student can easily jump to different modules at any time by pressing the “menu” button located in the top menu. Each module is followed by a quiz. After successful completion of all module quizzes (85% passing grade) the student will receive class credit. If a module quiz is failed, the student has the opportunity to review the module and retake that quiz. This is a self-paced course that may take several hours to complete. However, it is not necessary to complete the course at one time. This course will track progress, allowing students to leave the course and continue where they left off when they return within the next 90 days.

The “resources” button in the top menu contains additional and supporting materials. A printable version of the course can be found there, along with a glossary, a summary of useful links for codes and standards, a hydrogen properties fact sheet, a pressure safety study guide, a hydrogen embrittlement fact sheet, and a liquid hydrogen tank incident. Additional links relevant to hydrogen safety work are also listed.

The class was publicly released in September of 2010. Since then we have registered about 100 completions from multiple universities, government institutions, and private companies from five countries (USA, Canada, UK, Japan, and Mexico). Before public release, class materials were thoroughly reviewed by a panel of safety experts through two rounds of peer review, focusing on the technical aspects as well as in the teaching aspects of the class. Further improvement is always possible and we therefore invite all readers to take the class and submit comments to the authors that may improve the learning experience, update the class information. Class authors can be contacted by email at any time during the course, by clicking on the “help” button

### **3. HANDS-ON SAFETY CLASS**

In addition to the web-based fundamentals class, we are developing a hands-on hydrogen safety class for pressure operators. This comprehensive training includes basic hydrogen safety, regulators, relief devices, leak detection, and flash arrestors, followed by hands-on assembly and test of a hydrogen pressure system and a final evaluation. Training can be conducted during a three-day session at Lawrence Livermore National Laboratory, or at remote institutions if appropriate facilities (classroom, compressed gas supply, and pressure testing laboratory) exist.

The hands-on training class starts with a full day of classroom instruction covering essential topics of pressure system assembly and operation (Table 2). Classroom instruction focuses on identifying hazards, safety precautions, personal protective equipment, and pressurized hydrogen system components and their function. This class greatly expands the online hydrogen safety class, going into detailed operational information about every component in pressure systems, describing their inner functionality, applicability, and recommended use. Teaching is aided by segmented components that reveal their inner operational details (Figure 2). At the end of classroom instruction, students will be able to identify (i) the main pressurized hydrogen system components, (ii) pressure and hydrogen based hazards, (iii) the types of personal protective equipment that are used for pressurized hydrogen systems, and (iv) the pressurized hydrogen system component categories and their functions. In the final activity of the day, students are tested on the materials presented in the class.

Table 2. Structure of the hands-on safety class

**Modules**

<b>Day 1</b>	<b><i>Classroom Teaching</i></b>
	<ol style="list-style-type: none"> <li>1. Definitions</li> <li>2. Hazards</li> <li>3. Personal Protective Equipment</li> <li>4. Gas Cylinders</li> <li>5. Gas Cylinder Manifold</li> <li>6. Pressure Reducing Regulators</li> <li>7. Gauges/Pressure Transducers</li> <li>8. Regulator Safety Manifold</li> <li>9. Relief Devices</li> <li>10. Valves</li> <li>11. Fittings</li> <li>12. Tubing and Piping</li> <li>13. Flash Arrestors</li> <li>14. Quiz</li> </ol>
<b>Day 2</b>	<b><i>Pressure system assembly</i></b>
	Given a system schematic and description, select components, inspect and install, cut and bend tube, apply various fittings
<b>Day 3</b>	<b><i>System operation</i></b>
	Leak test using a mass spectrometer leak detector; setup data acquisition; conduct remote pressure test; leak test at maximum operating pressure using leak detector fluid; operate system to reach a desired pressure

Days two and three will be spent in the laboratory for practical application of the classroom information from day 1. On day two, students will be handed a safety document and instructed to assemble the pressure system described therein (Figure 3). Students will have to select, inspect and install pressure components, bend tube, install pipe and compression fittings, and assemble the entire system.

On day three this system will be leak checked with a mass spectrometer helium leak detector with a leak rate of no more than  $10^{-5}$  atm-cc/sec. The pressure system will then be connected to the data acquisition system and pressure tested remotely at 150% of the maximum allowable working pressure. The last leak test will be conducted using liquid leak detection fluid at the system's maximum operating pressure. Finally, the students will operate the system to reach a desired pressure.

During the two days of laboratory work, students will be tested as they build and test the system. On day two, tests will focus on correct system assembly (select appropriate components, inspect them, install them in the right place, bend tubing correctly, install plumbing at the correct place, and install compression fittings). On day three, students will be tested during leak checks and necessary system rebuilds to meet the leak test criterion. At the end day three, based on the successful completion of the assembled panel, students will be awarded a Certificate of Completion for "LLNL Hands-On Hydrogen Safety Training".

The hands-on class is still under development. Two working benches and instructional materials including segmented pressure components (regulators, valves, gauges, Fig. 2) have been prepared as teaching materials to best instruct component function. Classroom instruction materials are being prepared.

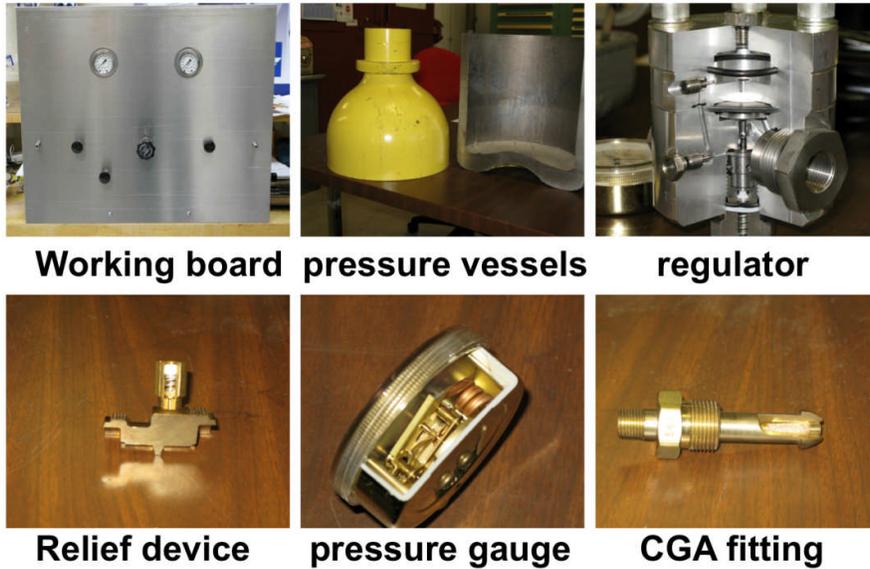


Figure 2. Working board and different pressure components segmented to illustrate internal structure and operability

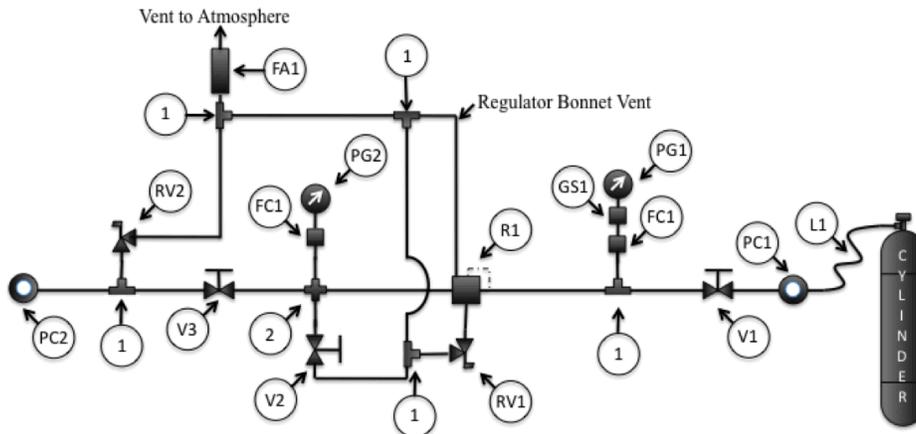


Figure 3. Piping and instrumentation diagram for the pressure system to be assembled during the hands-on hydrogen safety class

## CONCLUSIONS

Lawrence Livermore National Laboratory is contributing to safe hydrogen operations by developing instructional materials for researchers and technical operators:

- *Laboratory researchers* can obtain basic hydrogen safety information from a 4-hour web-based hydrogen safety class (free online access at <http://www.h2labsafety.org/>) addressing hydrogen fundamentals: properties, pressure and cryogenic safety, emergency response and codes and standards.
- *Technical operators* in charge of building and testing experimental hydrogen equipment may require more in-depth information than provided by the web-based class. We are therefore

preparing a 3-day hands-on safety class that presents detailed information for installation, testing and operation of hydrogen pressurized systems. The hands-on class includes a full day of classroom instruction followed by two days of laboratory work where students assemble, test and operate a pressure system based on a schematic and component description.

We strongly encourage participation of the members of the hydrogen community to improve the technical and educational aspects of the class by providing feedback and comments.

## **ACKNOWLEDGEMENTS**

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